Accuracy and Precision of an Intraoral Scanner in Complex Prosthetic Rehabilitations: an in Vitro Study

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Abstract

The main purpose of this study is to measure the accuracy and the precision of the intraoral optical scanner CS3500® (Carestream Dental LLC, Atlanta, USA) in complex clinical situations as full arch rehabilitations on implants.

50 scans of the acrylic resin model were performed by using CS3500® (Carestream Dental LLC, Atlanta, USA) scanner. Each scan was compared with the virtual model derived from scanning with the laboratory scanner Dscan3® (Enhanced Geometry Solution, Bologna, Italy) to measure a possible misalignment.

The alignment error was found to be 79,6 (± 12,87) μm. The measurement was taken at the level of 2 distal scan-abutments. The scanner's precision ranges from 24 to 52 μm , depending on the distance between scan-abutment.

CS3500® (Carestream Dental LLC, Atlanta, USA) intraoral scanner has detected a valid device in the execution of complex rehabilitations on implants. His accuracy and precision values fall within the range established in literature to define acceptable the prosthetic fitting on full arch implant rehabilitations.

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Introduction

The use of an intraoral optical scanner to detect impressions of dental arches is becoming increasingly prevalent in everyday clinical practice. The optical systems are capable of capturing and processing three-dimensional images of teeth and of edentulous areas that can be used either to create the accurate master models on which to work in the laboratory either for the manufacture of prosthetic articles directly. In the literature many studies compared the precision and accuracy of the different intraoral scanners.[1,2,3,4,5] However there are few studies about the accuracy of intraoral scanners in the full arch rehabilitations on implants. There is no protocols on how to determine and quantify the misfit of implants.[6,7] Accuracy is the average of the measurements; in fact, a measure is more accurate as the average of the measurements is approximated to the actual value of the magnitude. An intraoral scanner should therefore be accurate and possible by making a virtual 3D model as similar as possible to the real. In order to measure the accuracy is necessary to refer to a certain measurement, with margin of error tends to zero, that determined by laboratory extra-oral scanner. The more the software will be able to perform the matching between the captured images, the higher will be the accuracy of the scanner. The accuracy decreases as the amplitude of the scan. The accuracy is very high in the limited rehabilitation such as in the cases of single crowns or fixed prostheses confined in the half dental arch, but decreases in the rehabilitations that affect the full arch.[8] In addition to the accuracy and precision there are other fundamental parameters which characterize the different intraoral scanners, including the type of technology and the light source, the need for opacification of surfaces to be scanned, the size of the tip, color images or less, the open or closed system, and compatibility with milling

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chairside. The CS3500® (Carestream Dental LLC, Atlanta, USA) uses active triangulation technology and a structured light. The scanning surfaces do not require opacification. It also presents 2 scanning probes of different sizes (the largest for the anterior area and the smallest for the posterior). It develops color images and is an open system with an. stl file output. The study has the objective to evaluate the reliability of the scanning software and the acquisition of intraoral scanner CS3500® (Carestream Dental LLC, Atlanta, USA) in the reconstruction of three-dimensional virtual images in case of large areas of the edentulous maxilla with few landmarks.

Materials and methods

In a commercial acrylic resin model of edentulous maxilla were inserted 4 Biohorizons® (BioHorizons Inc, Alabama, USA) implants with a diameter of 3.8 mm in the area of the maxillary right first premolar, maxillary right lateral incisor, maxillary left lateral incisor and maxillary left firs premolar and 2 Winsix® (BioSAFin. S.r.l., Ancona, Italy) implants with a diameter of 4.5 mm in the area of the maxillary right first molar and maxillary left first molar (Fig.1).

A scan-abutment was screwed on each implant for the impression taking with the intraoral scanner CS3500® (Carestream Dental LLC, Atlanta, USA) (Fig.2). 50 scans of the model were made with the intraoral scanner CS3500® (Carestream Dental LLC, Atlanta, USA) by three experienced operators.

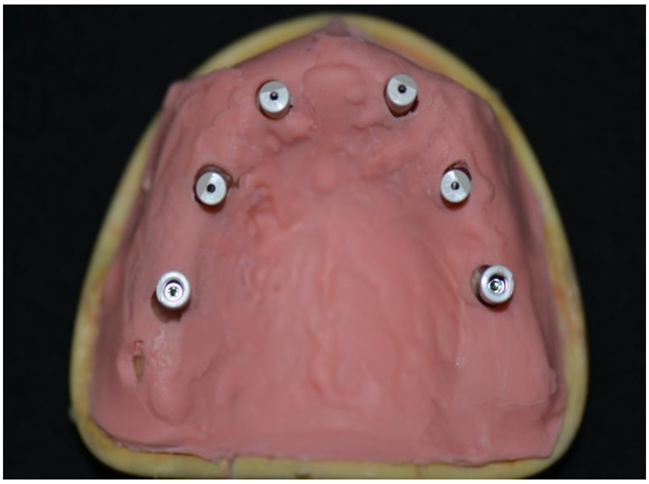

Figure 1. Acrylic resin model with scan-abutments used in the in vitro study.

SCANNING PROCEDURES

Scans were performed according to the instructions specified by the manufacturing company. CareStream CS3500® (Carestream Dental LLC, Atlanta, USA) system does not require a matting powder and is characterized by a scan with an inclination up to 45° and with a depth of field from -2 mm to +13 mm. The acquisition software which is fitted, the CS3500 Acquisition® (Carestream Dental LLC, Atlanta, USA), requires the overlapping of the images taken in sequence to about 50%, in order to facilitate the matching work. Scans were performed without the use of artificial light sources. At the end of each scan the “cloud of points” has been processed by the software that has generated a polygon mesh representing the fingerprint itself, which in turn was developed in a virtual model Solid To Layer (STL).

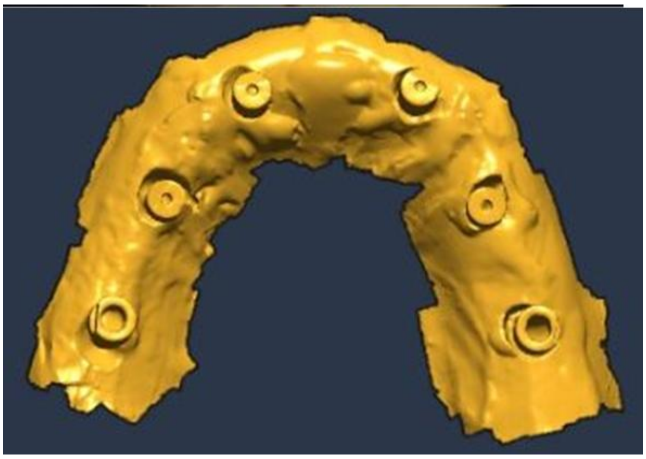

Figure 2. A scan of STL model using CS3500.

Figure 3. A scan of STL model using Dscan3 Laboratory.

3D ANALYSIS

To evaluate the accuracy of the scanner, each STL model derived from the 50 scans was compared to a STL model obtained from the scan of the original model with the laboratory extra-oral scanner DScan3® (Enhanced Geometry Solution, Bologna, Italy) which uses as acquisition software the DScan acquisition 5.0® (Enhanced Geometry Solution, Bologna, Italy) (Fig.3).

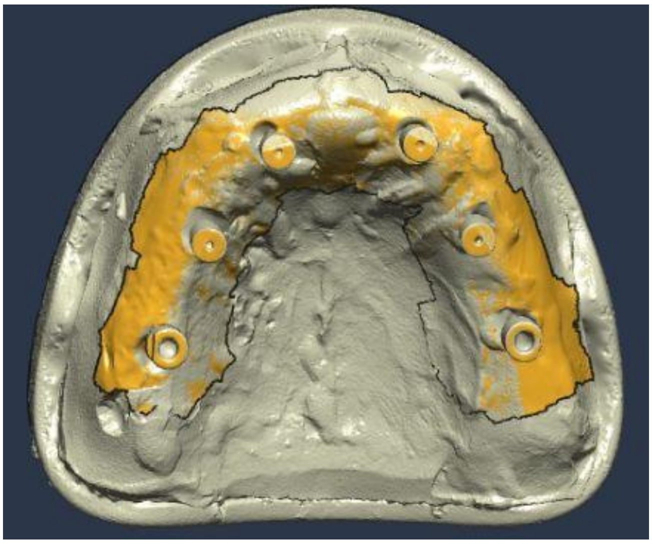

Figure 4. A scan of matching between STL models.

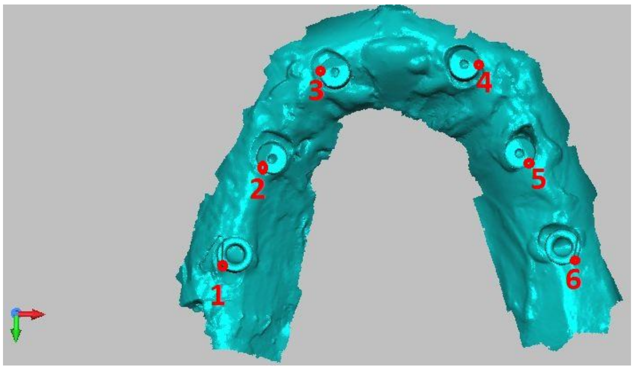

Figure 5. Reference points for the measurement of precision.

For the overlap of each of the 50 STL model with the STL reference model it has been used the EGS® (Enhanced Geometry Solutions, Bologna, Italy) software that has measured the alignment error between both models at the level of the scan-abutment and the false gum, with a precision of the order of 0.001mm (Fig.4). It was measured the alignment error between the two distal scan-abutments. Three experienced operators each performed measurements of the 50 STL models with the Exocad® (Exocad GmbH, Berlin, Germany) software, to assess the precision. It had been established a fixed point of reference for each of the 6-scan abutments. (Fig. 5). Point 1 of the scan-abutment in area of the maxillary right first molar was adopted conventionally as the center point of measurement and was calculated the distance of the points 2, 3, 4, 5, 6 from point 1 in each of the 50 STL models. Real and virtual images of scan-abutment are represented in Figure 6 (Fig. 6 A-B).

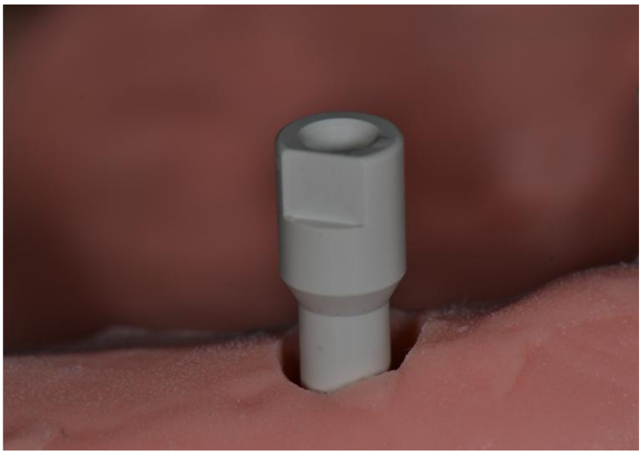

Figure 6 A. Real scan-abutment.

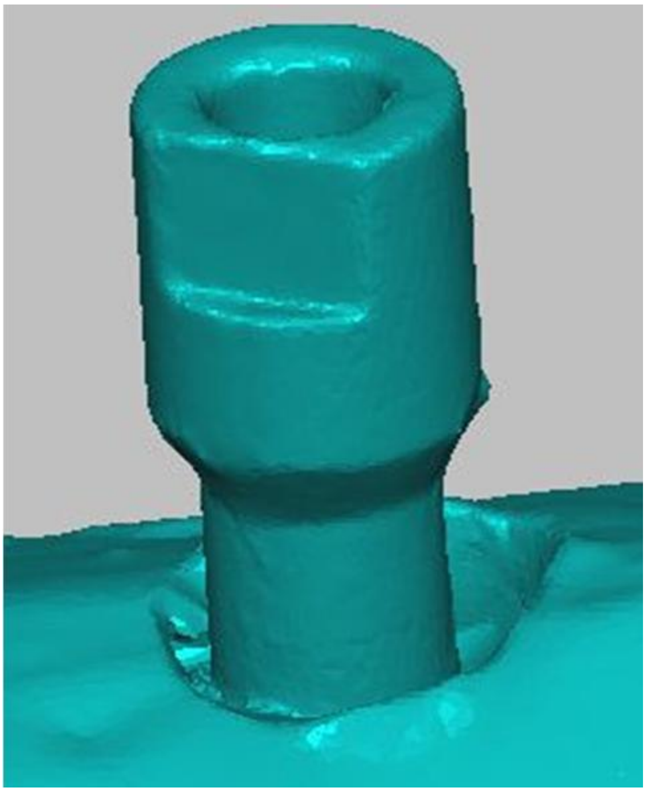

Figure 6 B. Virtual scan-abutment.

Statistical analysis

To evaluate the accuracy the arithmetic mean of the error of alignment of each of the 50 scans with the reference STL model was performed. To assess the precision the standard deviation of the arithmetic mean of measured values was calculated for each distance from point 1.

Results

Trueness

Values of the error of alignment between each of the 50 scans and the STL reference model are reported in Table 1. The average of the alignment error was 79,6 (± 12,87) μm. The maximum error value was 102 μm in the scan number 31. The minimum error value was 60 μm in the scan number 36.

Error/N.scan	Alignment error									
Number of scan	69/1	98/2	72/3	75/4	95/5	72/6	63/7	85/8	102/9	67/10
	69/11	82/12	74/13	65/14	69/15	98/16	79/17	82/18	61/19	96/20
	61/21	87/22	73/23	78/24	82/25	92/26	64/27	73/28	71/29	94/30
	102/31	69/32	61/33	83/34	99/35	60/36	84/37	71/38	90/39	67/40
	75/41	81/42	79/43	83/44	62/45	94/46	101/47	96/48	98/49	77/50

Table 1. Misalignment of each scan.

Precision

The precision values for each measured distance are shown in Table 2. The precision of calculated values vary from 24 to 52 μm. With increasing distance from point 1 the standard deviation of the measurements increases, indicating a loss of precision. A high precision was calculated in measurements inside the quadrant. In measurements between contralateral quadrant precision decreases.

Distance between scan-abutments	Arithmetical mean of measurements	Standard deviation (precision)
From 1.6 to 1.4	13,788 mm	24 μm
From 1.6 to 1.2	28,643 mm	27 μm
From 1.6 to 2.2	42,874 mm	35 μm
From 1.6 to 2.4	42,794 mm	42 μm
From 1.6 to 2.6	46,287 mm	52 μm

Table 2. Precision values for each measured distance.

Discussion

The main bias in the study in vitro is represented by the error of the extra-oral scanner Dscan3® (Enhanced Geometry Solution, Italy) laboratory. Mandelli et al in 2016[9] measured the accuracy of laboratory scanner DScan3® (Enhanced Geometry Solution, Bologna, Italy) and the result was 15,6 μm. It is difficult to determine an acceptable level of fit for implant supported prosthetic rehabilitation. According to Jemt et al[10] a discrepancy of fit below 150 μm does not involve any clinical complications. Other authors place this much more in the lower acceptability threshold, between 50 and 75 μm.[11,12,13]

A good prosthetic fit is essential for long-term success of the prosthetic rehabilitation. The CAD/CAM technology in dentistry has increased the accuracy of the structures than the traditional technique.[14] Despite the progress, the structures on implants realized with conventional impression technique, show the micro-gap further with increasing distance between the implants.[15] The misfit is largely caused by errors that occur during the traditional impression taking, development of the model plaster and the realization of the same structure.[16,17]

To eliminate these errors was introduced the concept of digital impression with intraoral scanner. It should replicate the original object the more thoroughly as possible, even when the scanning conditions are not optimal. The scan extension adversely affects the accuracy of the scanner. This could results from errors accumulated in the software matching process. The optical impression of an entire arch requires a greater number of acquisitions by the software and then a large number of image overlapping processes. Any error in each of these processes is in addition to those prior to reducing the level of accuracy of the scan.[18,19]

The wide scanning area and the lack of fixed reference points are the main causes of the reduction in the accuracy and precision of the intraoral scanner. In the literature there are many in vitro studies that measure the level of accuracy of different intraoral scanners. In vitro studies, however, do not take into account other variables that might occur in clinical practice, such as artifacts related to the movements of both the patient and operator, the limited ability of some patients to open his mouth, the mobility of the mucosa and the salivary flow. Results from in vitro studies can also be altered by the type of models used (partial or total), entity of the extension, the material of the reference models (plaster, metal, resin), from its reflective properties and the design of the scan-abutment.[2,4,20,21]

In the literature the majority of studies assesses the fit on single crowns on natural teeth. In these cases the accuracy of the intraoral scanner is greater than traditional impression.[22,23]

Few studies have been performed regarding rehabilitation on natural teeth of a full arch. Using a full-arch pattern resin containing 14 prepared dental elements, Patzel et al. in 2014[2,3] tested the accuracy of 4 intraoral scanner. The averages of the accuracies of the different scanners vary from 38 to 332,9 μm, while the precision range fluctuates from 37,9 to 99,1 μm.

Ender et al in 2015[24] evaluated several conventional impression materials and intraoral scanners. The digital impression of a full arch scored accuracy between 29 and 45 μm and the precision range lies between 19 and 63 μm.

These results are not significantly better than a traditional impression and the authors conclude that the intraoral scanner has demonstrated greater local deviation and that the accuracy depends largely on the scanning technique. Su and Sun in 2015[25] evaluated the accuracy of the Trios scanner comparing it with a laboratory scanner. It shows that not only the scanner is significantly less accurate, but the deviation increases with the increase of the number of teeth to be scanned. The digital impression detection with optical intraoral scanner of single implants is highly unpredictable as demonstrated by several studies and case reports in the literature.[26,27,28,29,30]

In the literature, however, there are few studies about the digital impression accuracy in total full-arch rehabilitation on implants. There is still no consensus on how determine and quantify the misfit of implant superstructures.[6,7] Moreover, there are additional errors during digital impression of multiple implants of an edentulous arch. When used as scan-abutment equal to each other the scanner has more difficulty to distinguish between them and identify their arch position. The intraoral scanner can paste the image of a scan-abutment on that of another.[31] Moreno et al[32] in 2013 measured in an in vitro study the accuracy of a full arch implant superstructure made of an STL model developed by a digital impression detected with a Lava COS® (3M ™ ESPE, Seefeld, Germany) scanner system. The error maintained below 100 μm.

The superstructure was subsequently screwed on the model obtaining a satisfactory fit. Gimenez et al in 2015[8] have scanned with the Cerec BlueCam® (Sirona Dental System GmbH, Bensheim, Germany) an edentulous jaw model with 6 implants. Although the first quadrant is very accurate result, the accuracy has deteriorated significantly in the scan of the second quadrant.

Papaspyridakos et al in 2015[7] compared the Trios® (3Shape A/S, Copenhagen, Denmark) intraoral scanning system with different conventional polyether impressions both splinted and not on an edentulous jaw with 5 implants. In this study it was not a significant difference between the traditional and digital impression. The average of deviation for the Trios® (3Shape A/S, Copenhagen, Denmark) was 19.18 μm. In this study have been used laboratory scan-abutment longer than those intraoral.

Stielmayer et al in 2012[33] reported a significant difference of accuracy between intraoral scan-abutment than those of laboratory, in favor of the later.

As reported by Fluegge et al in 2015 [34] in case of intraoral scan-abutment smaller and shorter, the accuracy decreases. In a study of 2016 Vandeweghe et al[35] evaluated in vitro the accuracy of the scanners Lava COS® (3M ™ ESPE, Seefeld, Germany), True Definition® (3M ™ ESPE, Seefeld, Germany), Cerec Omnicam® (Sirona, Long Island City, New York, USA) and Trios® (3Shape A/S, Copenhagen, Denmark). They performed with each scanner 10 scans of a mandibular model in acrylic resin with six scan-abutment and have compared with a STL model obtained with a laboratory scanner. The average alignment error was 112 μm for the Lava COS® (3M ™ ESPE, Seefeld, Germany), 35 μm for the True Definition® (3M ™ ESPE, Seefeld, Germany), 28 μm for the Trios® (3Shape A/S, Copenhagen, Denmark) and 61 μm for the Omnicam® (Sirona, Long Island City, New York, USA). Another important difference between the different scanners is the use of the opacifying powder.

Looking at the results of the studies there seems to be no difference between systems with powder than those without powder. It can be stated with certainty that in the case of reflecting or translucent surfaces the use of the opacifying powder increases the level of accuracy of digital impressions.[1]

Conclusions

Within the limits of this study, CS3500® (Carestream Dental LLC, USA) has demonstrated an acceptable level of accuracy in full-arch rehabilitations on implants. Furthermore the level of accuracy relative to the digital impression is quite comparable to the traditional impression. The purpose of the study was to evaluate the potential and limitations of the CS3500® (Carestream Dental LLC, USA) to perform an in vivo study further forward where will meet the difficulties related to the oral environment[36] and also to the scanning surfaces that may change depending on the movements of the arches at the level of the median and lateral frenula. This could be a problem during the acquisition because the software uses fixed landmarks to perform the matching between the various acquisitions[31].

Similarly a greater inter-implant distance along with a flat ridge may increase the errors in the acquisition phase, as they reduce the reference points for matching.[8]

The distance between implants may be greater in vivo compared to in vitro model and this would increase the difficulty in scanning, thus reducing the accuracy of the virtual model.

Declaration of Interest

The authors report no conflict of interest and the article is not funded or supported by any research grant.

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